Are the faecal pellets of kangaroos (*Macropus* spp.) a source of nutrients and carbon in an inland floodplain wetland during flooding? A preliminary experimental inundation study in the Macquarie Marshes, New South Wales

Tsuyoshi Kobayashi, Jordan Iles, and Lisa Knowles

NSW Department of Environment, Climate Change and Water, PO Box A290 Sydney South NSW, 1232.
Correspondence author: Yoshi.Kobayashi@environment.nsw.gov.au

ABSTRACT

Kangaroos (*Macropus* spp.) are one of the most abundant native macrofauna on Australian floodplains with a positive relationship between their density and the deposition of faecal pellets that contain nutrients and carbon. We tested whether kangaroo faecal pellets are a source of nutrients and carbon during flooding in the Macquarie Marshes, an inland floodplain wetland, in south-eastern Australia. The faecal pellets of kangaroos, most likely of Red Kangaroo (*M. rufus*), were found on the dry floodplain adjacent to Bora Channel (~30.6433°S/~147.5351°E) at a density of 142±54 m^{-2} (mean±SE, *n*=3). Following artificial inundation, we monitored the release of total nitrogen (TN), total phosphorus (TP) and dissolved organic carbon (DOC) five times over a six-day period from mesocosms deployed *in situ*. Three mesocosms contained faecal pellets and three mesocosms contained marsh floodplain sediments (top 5 cm of sediment consisting of soils and plant material) with faecal pellets removed. The concentrations (mean±SE, *n*=3) of TN, TP and DOC in the mesocosms containing the pellets were 0.037±0.017, 0.22±0.060 and 0.69±0.14 g m^{-2} at day 6, while the mesocosms containing only the marsh floodplain sediments were 1.03±0.23, 0.49±0.083 and 7.27±1.02 g m^{-2}. On average, the kangaroo faecal pellets contributed ~6% of TN, ~31% of TP and ~ 8% of DOC of the total amounts respectively released from the inundated floodplain over the six-day experiment. Nutrient and carbon depositions to floodplains in the form of faecal pellets from large terrestrial animals such as kangaroos are an important process of cycling these elements in inland floodplain wetlands, especially where large populations of these animals occur.

Key words: inland floodplain wetlands, elemental cycling, autotrophic and heterotrophic sources, Red Kangaroo, Eastern Grey Kangaroo

Introduction

The availability of water affects the ecosystem properties (e.g. food webs and nutrient cycling) of floodplain wetlands (Kingsford 2000; Junk and Wantzen 2004; Wilson *et al.* 2010; Kelleway *et al.* 2010; Kobayashi *et al.* 2010). During dry periods, floodplain wetlands are largely terrestrial systems where plant material such as leaf litter, twigs, and animal faecal pellets accumulate (Robertson *et al.* 1999; Baldwin 1999; Junk and Wantzen 2004; Kobayashi *et al.* 2009; Iles *et al.* 2010). Plant material that accumulates on floodplains is a significant source of nutrients and carbon for aquatic wetland communities during flooding (Baldwin 1999; Baldwin and Mitchell 2000).

Kobayashi *et al.* (2009, page 853) speculated on the potential contribution of animal faecal pellets to floodplain nutrient and carbon dynamics. Kangaroos such as Western Grey Kangaroo (*Macropus fuliginosus*), Eastern Grey Kangaroo (*M. giganteus*) and Red Kangaroo (*M. rufus*) are the dominant native macrofauna on Australian floodplains (Cairns and Grigg 1993; Strahan 1995; McCarthy 1996; Jonzén *et al.*, 2005). There is a positive relationship between their density and the deposition of faecal pellets (Southwell 1989; Johnson and Jarman 1987; Ramp and Coulson 2004). The faecal pellets of kangaroos contain nutrients such as nitrogen and phosphorus, and carbon in the form of carbohydrates (Hume 1974; Wann and Bell 1997) that derive from their food such as grasses, flowering plants, forbs, leaves, tree bark and shrubs (Taylor 1983; Short 1986; Meers and Adams 2003; Murphy and Bowman 2007). Kangaroos can travel large distances (Priddel *et al.* 1988; Jaremovic and Croft 1987; Pople *et al.* 2007) and use different habitats (Johnson *et al.* 1987; Priddel 1988; Murphy and Bowman 2007). They may play a significant role in nutrient and carbon cycling in inland floodplain wetlands of Australia. However, it is unknown whether kangaroo faecal pellets deposited on floodplains are another significant source of nutrients and carbon that can be used by aquatic wetland communities (e.g. bacteria, algae and vascular plants) during flooding (Robertson *et al.* 1999; Kobayashi *et al.* 2009; Wilson *et al.* 2010). In the present study, we tested whether the faecal pellets of kangaroos, most likely of Red Kangaroo (*Macropus rufus*) deposited on floodplains of the Macquarie Marshes, New South Wales, are a source of nutrients and carbon for overlaying floodwater following inundation.

Materials and Methods

The Macquarie Marshes (total area: ~210,000 ha) are in the north-west of the Macquarie River catchment and form one of the largest floodplain wetlands in the Murray-Darling Basin of south-eastern Australia. The Marshes are a mosaic of inland floodplain swamps, shrub lands, woodlands and inland riverine forests (Keith 2004). The system contains two major nature reserves (Southern and Northern Nature Reserves) each with internationally significant wetlands listed under the Ramsar Convention (Kingsford and Thomas 1995).

Populations of Red Kangaroos and Eastern Grey Kangaroos have been recorded in the Macquarie Marshes (NSW NPWS 1993). Censuses of macropods in 1992 and 1993 estimated the average total number of kangaroos to be ~5,000 and ~10,000 in the Southern and Northern Nature Reserves respectively (~1 kangaroo ha^{-1} in both reserves) (Darren Shelly, DECCW, pers. comm. 2010).

Study site

An experiment was undertaken between 22 and 28 February 2007 on a floodplain (~30.6433°S/~147.5351°E) near Bora channel in the Northern Nature Reserve, which excluded human activities including grazing (see Fig. 1 in Kobayashi *et al.* 2007 for the study area details).

Mesocosms *in situ* and collection of water samples from the mesocosms

A total of seven mesocosms were deployed at a dry floodplain site. Each mesocosm was comprised of a polyvinyl chloride (PVC) pipe, 30 cm in diameter and 25 cm in height. The pipe was thoroughly washed with tap water, rinsed with Milli-Q water (Millipore, USA: 0.2 μm) and air-dried before being deployed. In the field, three mesocosms were constructed by pushing the PVC pipes into the sediment to a depth of 5 cm. The sediment surrounding each mesocosm was removed and a thin steel plate was inserted underneath the pipe to isolate the sediment in the mesocosm and to maintain a 5 cm deep sediment core inside it. The mesocosm was lifted and placed on a plastic sheet. After removing the steel plate, a plastic sheet was wrapped around the base of the mesocosm and secured with duct tape to prevent water leakage. From each of the three mesocosms, kangaroo faecal pellets were counted, removed and then transferred to each of the other three mesocosms that had been constructed only from the PVC pipe and plastic sheet.

To measure the release of nutrients and carbon from the faecal pellets and floodplain sediments (i.e. soils and plant material) following inundation, rainwater stored in a local household rainwater tank was used. The rainwater initially contained 1.11±0.007 mg l^{-1} of TN, 0.021±0.0003 mg l^{-1} of TP and 1.37±0.05 mg l^{-1} of DOC (mean±SE, n=3). With a plastic watering can, a total of 7 L of rainwater was gently added to each mesocosm. One additional mesocosm constructed of PVC pipe and plastic sheet with rainwater added was used as a control. A total of seven mesocosms (i.e. three mesocosms with faecal pellets and rainwater, three mesocosms with floodplain sediments and rainwater, and one mesocosm with rainwater) were placed approximately 5 m apart on the open Bora Channel floodplain. The top of each mesocosm was covered with a 10 mm mesh net to prevent water access by animals during the experiment.

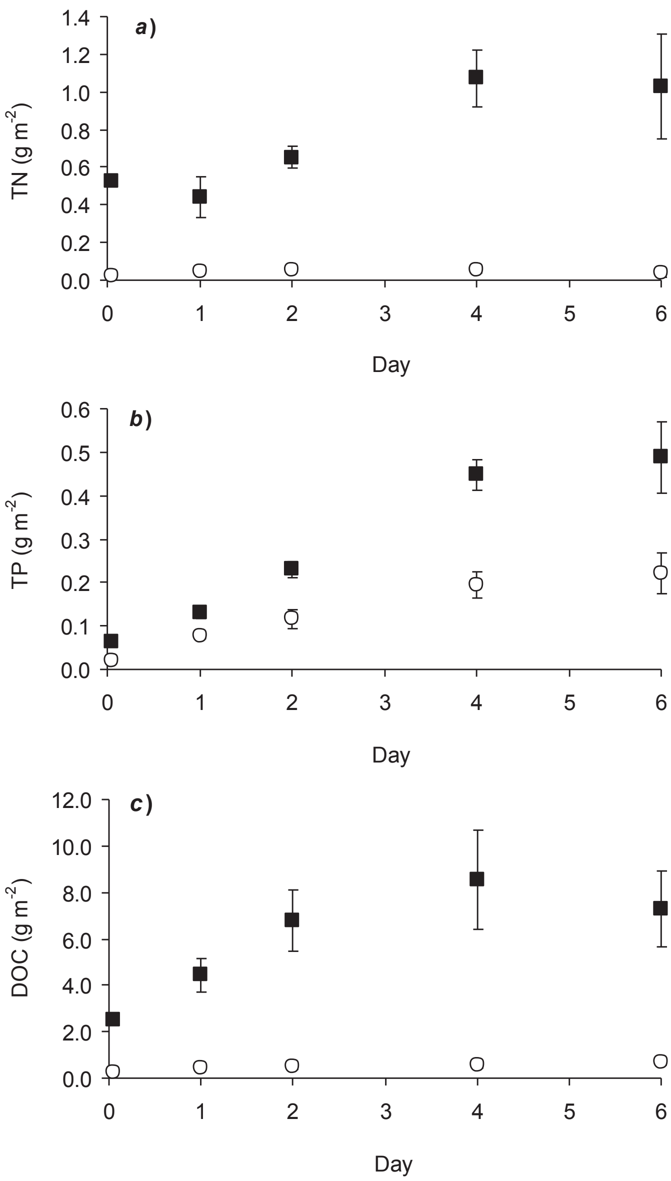

Figure 1. Concentrations of a) total nitrogen (TN), b) total phosphorus (TP) and c) dissolved organic carbon (DOC) released from Bora Channel floodplain. ■, sediments (soils plus plant matter); O, kangaroo faecal pellets. Arithmetic mean ± standard error (SE) are shown (n = 3 for each observation).

Two 30 ml water samples were collected from each mesocosm with a sterile syringe (Termo, USA) approximately 1 hour after the addition of rainwater to the mesocosm, then at days 1, 2, 4 and 6. At each sample collection, one water sample was filtered immediately through a cellulose acetate filter (pore size: 0.45 μm, Sartorius, Germany) and used to determine DOC; the other water sample was unfiltered and used to determine TN and TP. All water samples were stored at –20 °C until analysed.

Laboratory Methods

A flow injection analysis was used to determine the concentrations of nutrients. TN was measured following autoclave persulfate digestion (Hosomi and Sudo 1986). TP was measured by the ascorbic acid reduction method following autoclave persulfate digestion. A Lachat QuikChem 8000 flow injection analyser (Hach Company, USA) was used for all nutrient analyses. DOC was analysed using a Dohrmann TOC analyser. The concentrations of TN, TP and DOC were expressed as g m^{-2} after subtracting the initial concentrations of TN, TP and DOC contained in the rainwater. Kangaroo faecal pellet density calculated from the three mesocosms was converted into number of pellets m^{-2}.

Results

Kangaroo faecal pellets on the floodplain

Kangaroo faecal pellets were at a density of 142±54 m^{-2} (mean±SE, n=3) on the studied area of the floodplain. The pellets were most likely from Red Kangaroo (Barbara Triggs, personal communication).

TN, TP and DOC in the mesocosms with kangaroo faecal pellets

The concentrations (mean±SE, n=3) of nutrients and DOC in the overlaying water of the mesocosms containing only the pellets increased during the incubation period, attaining 0.037±0.017 g m^{-2} (1.11±0.52 mg l^{-1} in the mesocosms) of TN, 0.22±0.060 g m^{-2} (6.69±1.82 mg l^{-1}) of TP and 0.69±0.14 g m^{-2} (20.81±4.23 mg l^{-1}) of DOC at day 6 (Fig. 1). A single kangaroo faecal pellet was estimated to release 0.33±0.007 mg of TN, 0.54±0.07 mg of TP, and 3.3±0.6 mg of DOC during the first day (24 h) of inundation.

TN, TP and DOC in the mesocosms with sediments (containing soil and plant material but with kangaroo faecal pellets removed)

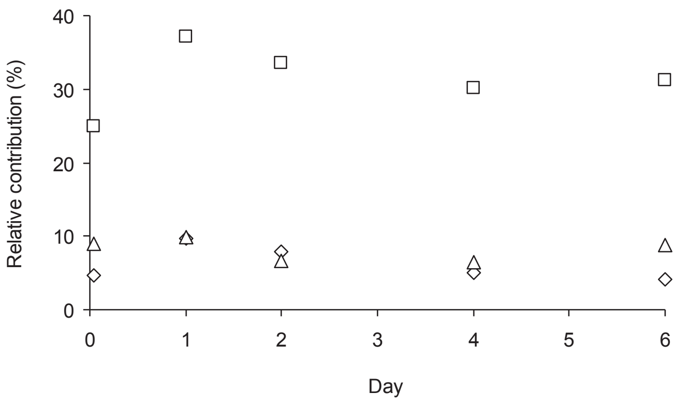

Figure 2. Relative contribution (%) of kangaroo faecal pellets to the total concentration of nutrients and carbon released from Bora Channel floodplain (sum of soils, plant matter and kangaroos faecal pellets). ◇, total nitrogen (TN); □, total phosphorus (TP); Δ, dissolved organic carbon (DOC). Arithmetic means are shown (n = 3 for each observation).

The concentrations (mean±SE, n=3) of nutrients and DOC in the overlaying water of the mesocosms with the sediments increased during the incubation period, attaining 1.03±0.23 g m^{-2} (7.27±1.61 mg l^{-1} in the mesocosms) of TN, 0.49±0.083 g m^{-2} (3.46±0.59 mg l^{-1}) of TP and 7.27±1.02 g m^{-2} (51.14±7.17 mg l^{-1}) of DOC at day 6 (Fig. 1).

Relative contributions of kangaroo faecal pellets to the total release of TN, TP and DOC

Relative (%) contributions of kangaroo faecal pellets to the total amount of nutrients and DOC released from the floodplain (i.e. sum of soil, plant material and pellets) were estimated as 6.3±1.1% of TN, 31.4±2.0% of TP and 8.1±0.68% of DOC (mean±SE, n=15 for each) over the 6-day experiment (Fig. 2).

Control mesocosm

The concentrations of TN, TP and DOC in the control mesocosm (rainwater only) changed very little (< ±3% of the initial concentrations) over the 6-day experiment.

Discussion

The experiment showed that kangaroo faecal pellets deposited on floodplains release nutrients and carbon to the overlaying water during flooding and can potentially provide a significant portion of phosphorus relative to nitrogen and carbon. In the studied area of the floodplain in the Macquarie Marshes, kangaroo faecal pellets contributed ~30% of TP into the overlaying water during the first six days of inundation, while the floodplain sediment (soil and plant material) was the major source (>90%) of TN and DOC.

The relative importance of animal faecal pellets to the total floodplain resource pool (nitrogen, phosphorus and carbon in this study) will vary temporally and spatially, depending on the type, density and biomass of animal faecal pellets (Ramp and Coulson 2004), animal diet (Hume 1974), the type, biomass and age of plant litter (Robertson *et al.* 1999; Baldwin 1999), soil composition (Kobayashi *et al.* 2009; Wilson *et al.* 2010), history of flooding (Baldwin and Mitchell 2000) and microbial processes (Wilson *et al.* 2010). Clearly, further studies are needed to determine the significance of the nutrients and carbon released from the pellets to the total resource pool across the floodplain. Nevertheless, the results of the present study support the hypothesis that allochthonous heterotrophic sources such as kangaroo faecal pellets can be a source of nutrients and carbon to aquatic communities during flooding on floodplains, as postulated by Kobayashi *et al.* (2009, page 853). We further hypothesize that the distribution and productivity of food sources and water availability for kangaroos across the floodplain are important in determining the nutrient and carbon supplies from kangaroo faecal pellets. This is because environmental conditions affect densities of kangaroo populations, as well as their home range movements and feeding habitats (Caughley *et al.* 1985; Johnson *et al.* 1987; Dawson *et al.* 2004; Pople *et al.* 2007).

Terrestrial and aquatic systems alternate in floodplain wetlands. During flooding, a spatial loss of terrestrial habitats equates to the spatial gain of aquatic habitats. Little is known about the effect of these changes in floodplain habitats on the ecological processes of resident biological communities (Junk and Wantzen 2004). Such information is critical to better understand the impacts of changes in ecosystem connectivity on inland floodplain wetlands. The connectivity of these systems has been altered by regulation and water extraction which may exacerbate the ecological stress exhibited on these systems (Kingsford 2000; Junk and Wantzen 2004). Results from this study indicate that the ecological role of terrestrial macrofauna on aquatic processes during wet periods warrants further investigation.

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References

Baldwin, D.S. 1999. Dissolved organic matter and phosphorus leached from fresh and 'terrestrially' aged River Red Gum leaves: implications for assessing river-floodplain interactions. *Freshwater Biology* **41**: 675-685.

Baldwin, D.S. and Mitchell, A.M. 2000. The effects of drying and re-flooding on the sediment and soil nutrient dynamics of lowland river-floodplain systems: a synthesis. *Regulated Rivers: Research and Management* **16**: 457-467.

Cairns, S.C. and Grigg, G.C. 1993. Population dynamics of red kangaroos (*Macropus rufus*) in relation to rainfall in the South Australian pastoral zone. *Journal of Applied Ecology* **30**: 444-458.

Caughley, G., Griggs, G.C. and Smith, L. 1985. The effect of drought on kangaroo populations. *The Journal of Wildlife Management* **49**: 679-685.

Dawson T.J., McTavish, K.J. and Ellis, B.A. 2004. Diets and foraging behaviour of red and eastern grey kangaroos in arid shrub land: is feeding behaviour involved in the range expansion of the eastern grey kangaroo into the arid zone? *Australian Mammalogy* **26**: 169-178.

Hosomi, M. and Sudo, R. 1986. Simultaneous determination of total nitrogen and total phosphorus in freshwater samples using persulfate digestion. *International Journal of Environmental Studies* **27**: 267-275.

Hume, I.D. 1974. Nitrogen and sulphur retention and fibre digestion by euros, red kangaroos and sheep. *Australian Journal of Zoology* **22**: 13-23.

Iles, J., Kelleway, J. Kobayashi, T., Mazumber, D., Knowles, L., Priddel, D. and Saintilan, N. 2010. Grazing kangaroos act as local recyclers of energy on semiarid floodplain. *Australian Journal of Zoology* **58**: 145-149.

Jaremovic, R.V. and Croft, D.B. 1987. Comparison of techniques to determine eastern grey kangaroo home range. *The Journal of Wildlife Management* **51**: 921-930.

Johnson, C.N. and Jarman, P.J. 1987. Macropod studies at Wallaby Creek. VI. A validation of the use of dung-pellet counts for measuring absolute densities of populations of macropodids. *Australian Wildlife Research* **14**: 139-145.

Johnson, C.N., Jarman, P.J. and Southwell, C.J. 1987. Macropod studies at Wallaby Creek. V. Patterns of defaecation by eastern grey kangaroos and red-necked wallabies. *Australian Wildlife Research* **14**: 133-138.

Jonzén, N., Pople, A.R., Grigg, G.C. and Possingham, H.P. 2005. Of sheep and rain: large-scale population dynamics of the red kangaroo. *Journal of Applied Ecology* **74**: 22-30.

Junk, W.J. and Wantzen, K.M. 2004. The Flood Pulse concept: new aspects, approaches and applications- an update. pp. 117-140 in Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2, edited by R.L. Welcomme and T. Petr. Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17.

Keith, D.A. 2004. Ocean Shores to Desert Dunes: The Native Vegetation of New South Wales and the ACT. Department of Environment and Conservation (Sydney, NSW).

Kelleway, J., Mazumder, D., Wilson, G.G., Saintilan, N., Knowles, L., Iles, J. and Kobayashi, T. 2010. Trophic structure of benthic resources and consumers varies across a regulated floodplain wetland. *Marine and Freshwater Research* **61**: 430-440.

Kingsford, R.T. 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* **25**: 109-127.

Kingsford, R.T. and Thomas, R.F. 1995. The Macquarie Marshes in arid Australia and their waterbirds: A 50-year history of decline. *Environmental Management* **19**: 867-878

Kobayashi, T., Shiel, R.J. and Segers, H. 2007. First record of the rotifer *Lecane shieli* Segers & Sanoamuang, 1994 from Australia. *Australian Zoologist* **34**: 181-183.

Kobayashi, T., Ryder, D.S., Gordon, G., Shannon, I., Ingleton, T., Carpenter, M. and Jacobs, S.J. 2009. Short-term response of nutrients, carbon and planktonic microbial communities to floodplain wetland inundation. *Aquatic Ecology* **43**: 843-858.

Kobayashi, T., Ryder, D.S., Ralph, T.J., Mazumder, D., Saintilan, N., Iles, J., Knowles, L., Thomas, R. and Hunter, S. 2010. Longitudinal spatial variation in ecological conditions in an in-channel floodplain river system during flow pulses. *River Research and Applications*. DOI: 10.1002/rra.1381

McCarthy, M.A. 1996. Red kangaroo (*Macropus rufus*) dynamics: effects of rainfall, density dependence, harvesting and environmental stochasticity. *Journal of Applied Ecology* **33**: 45-53.

Meers, T. and Adams, R. 2003. The impact of grazing by Eastern Grey Kangaroos (*Macropus giganteus*) on vegetation recovery after fire at Reef Hills Regional Park, Victoria. *Ecological Management and Restoration* **4**: 126-132.

Murphy, B.P. and Bowman, D.M.J.S. 2006. The interdependence of fire, grass, kangaroos and Australian Aborigines: a case study from central Arnhem Land, northern Australia. *Journal of Biogeography* **34**: 237-250.

NSW NPWS. 1993. Macquarie Marshes Nature Reserve Plan of Management. NSW National Parks and Wildlife Service, May 1993, ISBN 0 7305 7351 6.

Pople, A.R., Phinn, S.R., Menke, N., Grigg, G.C., Possingham, H.P. and McApline, C. 2007. Spatial patterns of kangaroo density across the South Australian pastoral zone over 26 years: aggregation during drought and suggestions of long distance movement. *Journal of Applied Ecology* **44**: 1068-1079.

Priddel, D. 1988. Habitat utilisation by sympatric red kangaroos *Macropus rufus*, and western grey kangaroos *M. fuliginosus*, in western New South Wales. *Australian Wildlife Research* **15**: 413-421.

Priddel, D., Shepherd, N. and Wellard, G. 1988. Home ranges of sympatric red kangaroos *Macropus rufus*, and western grey kangaroos *M. fuliginosus*, in Western New South Wales. *Australian Wildlife Research* **15**: 405-411.

Ramp, D. and Coulson, G. 2004. Small-scale patch selection and consumer-resource dynamics of eastern grey kangaroos. *Journal of Mammalogy* **85**: 1053-1059.

Robertson, A.I., Bunn, S.E., Boon, P.I. and Walker, K.F. 1999. Sources, sinks and transformations of organic carbon in Australian floodplain rivers. *Marine and Freshwater Research* **50**: 813-829.

Short, J. 1986. The effect of pasture availability on food intake, species selection and grazing behaviour of kangaroos. *Journal of Applied Ecology* **23**: 559-571.

Southwell, C. 1989. Techniques for monitoring the abundance of kangaroo and wallaby populations. In 'Kangaroos, Wallabies, and Rat Kangaroos'. G. Grigg, P. Jarman and I.D. Hume, Eds. pp 659-693. (Surrey Beatty & Sons, Sydney, Australia.)

Strahan, R. (editor) 1995. *The Mammals of Australia*. Reed Books, Chatswood, NSW.

Taylor, R.J. 1983. The diet of eastern grey kangaroo and wallaroo in areas of improved and native pasture in the New England Tablelands. *Australian Wildlife Research* **10**: 203-211.

Wann, J.M. and Bell, D.T. 1997. Dietary preferences of the black-gloved wallaby (*Macropus irma*) and the western grey kangaroo (*M. fuliginosus*) in Whiteman Park, Perth, Western Australia. *Journal of the Royal Society of Western Australia* **80**: 55-62.

Wilson, J.S., Baldwin, D.S., Rees, G.N. and Wilson, B.P. 2010. The effects of short-term inundation on carbon dynamics, microbial community structure and microbial activity in floodplain soil. *River Research and Applications*. DOI: 10.1002/rra.1352.